User's Guide
SNVA628A – January 2012 – Revised May 2013

AN-2213 LM5045 Based 240W Power Converter Using Full-Wave Rectification on the Secondary

1 Introduction

The LM5045 based 240W reference board is designed to evaluate the performance of the full-wave rectification scheme on the secondary side. The reference board is designed in an industry standard quarter brick footprint.

The performance of the evaluation board is as follows:

- Input operating range: 36V to 75V
- Output voltage: 12V
- Measured efficiency at 48V: 94.8% @ 20A with a peak of 95.2%
- Frequency of operation: 400 kHz
- Board size: 2.28 x 1.45 x 0.5 inches
- Load Regulation: 0.2%
- Line Regulation: 0.1%
- Line UVLO (34V/32V on/off)
- Hiccup Mode Current Limit

The printed circuit board consists of 6 layers; 2 ounce copper outer layers and 3 ounce copper inner layers on FR4 material with a total thickness of 0.062 inches. The unit is designed for continuous operation at rated load at <40°C and a minimum airflow of 200 CFM.

2 Theory of Operation

Power converters based on the full-bridge topology offer high-efficiency and good power handling capability up to 1kW. Figure 1 illustrates the circuit arrangement for the full-bridge topology with full-wave rectification. The switches, in the diagonal, Q1,Q3 and Q2,Q4 are turned alternatively with a pulse width determined by the input and output voltages and the transformer turns ratio. Each diagonal (Q1 and Q3 or Q2 and Q4), when turned ON, applies input voltage to the primary of the transformer. The resulting secondary voltage is then full-wave rectified and filtered with an LC filter to provide a smoothened output voltage. The full-wave rectification on the secondary is a good alternative to the center-tapped rectification for high output voltages. The ratings of the synchronous MOSFETs are at least half that of the center-tapped arrangement. Lower the maximum VDS rating, better the $Q*R_{DSON}$ figure of merit and therefore leading to better efficiency. Further in a full-bridge topology, the primary switches are turned on alternatively energizing the windings in such a way that the flux swings back and forth in the first and the third quadrants of the B-H curve. The use of two quadrants allows better utilization of the core resulting in a smaller core volume compared to the single-ended topologies such as a forward converter.

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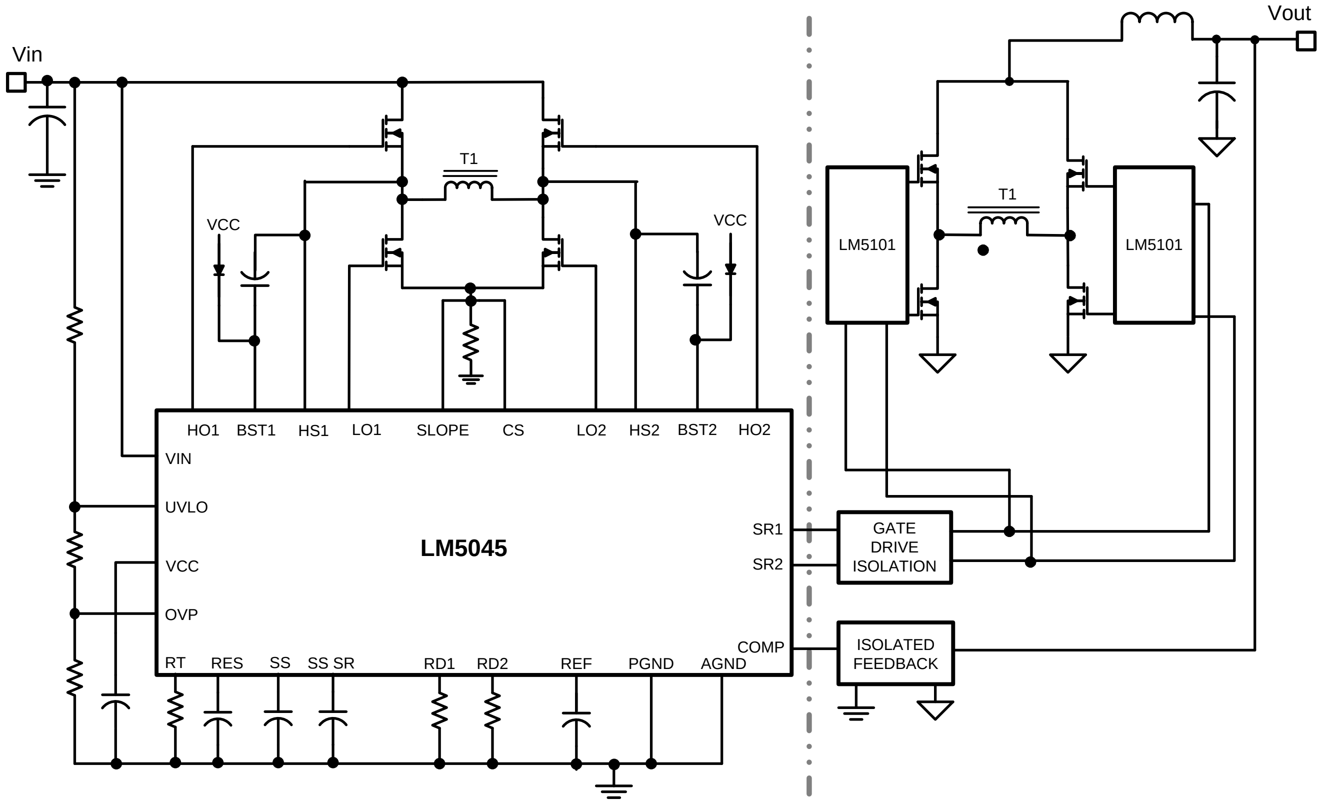

Figure 1. Simplified Full-Bridge Converter with Full-Wave Rectification

The secondary side employs full-wave synchronous rectification scheme, which is controlled by the LM5045. In addition to the basic soft-start already described, the LM5045 contains a second soft-start function that gradually turns on the synchronous rectifiers to their steady-state duty cycle. This function keeps the synchronous rectifiers off during the basic soft-start allowing a linear start-up of the output voltage even into pre-biased loads. Then the SR output duty cycle is gradually increased to prevent output voltage disturbances due to the difference in the voltage drop between the body diode and the channel resistance of the synchronous MOSFETs. Once, the soft-start is finished, the synchronous rectifiers are engaged with a non-overlap time programmed by the RD1 and RD2 resistors. Feedback from the output is processed by an amplifier and reference, generating an error voltage, which is coupled back to the primary side control through an opto-coupler. The LM5045 evaluation board employs peak current mode control and a standard “type II” network is used for the compensator.

3 Powering and Loading Considerations

When applying power to the LM5045 240W evaluation board certain precautions need to be followed. A misconnection can damage the assembly.

4 Proper Connections

When operated at low input voltages the evaluation board can draw up to 7.5A of current at full load. The maximum rated output current is 20A. Be sure to choose the correct connector and wire size when attaching the source supply and the load. Monitor the current into and out of the evaluation board. Monitor the voltage directly at the output terminals of the evaluation board. The voltage drop across the load connecting wires will give inaccurate measurements. This is especially true for accurate efficiency measurements.

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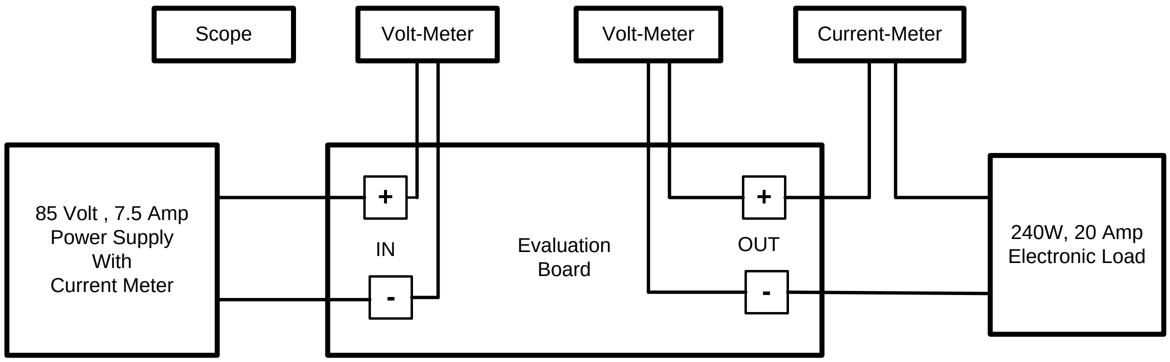
5 Source Power

The evaluation board can be viewed as a constant power load. At low input line voltage (36V) the input current can reach 7.5A, while at high input line voltage (72V) the input current will be approximately 3.5A. Therefore, to fully test this LM5045 reference board a DC power supply capable of at least 85V and 8A is required. The power supply must have adjustments for both voltage and current.

The power supply and cabling must present low impedance to the evaluation board. Insufficient cabling or a high impedance power supply will droop during power supply application with the evaluation board inrush current. If large enough, this droop will cause a chattering condition upon power up. This chattering condition is an interaction with the evaluation board under voltage lockout, the cabling impedance and the inrush current.



6 Loading

An appropriate electronic load, with specified operation down to 3.0V minimum, is desirable. The resistance of a maximum load is 0.6Ω. The high output current requires thick cables! If resistor banks are used there are certain precautions to be taken. The wattage and current ratings must be adequate for a 20A, 240W supply. Monitor both current and voltage at all times. Ensure that there is sufficient cooling provided for the load.

7 Air Flow

Full power loading should never be attempted without providing the specified 300 LFM of air flow over the evaluation board. A stand-alone fan should be provided.

8 Powering Up

It is suggested that the load be kept low during the first power up. Set the current limit of the source supply to provide about 1.5 times the wattage of the load. As soon as the appropriate input voltage is supplied to the board, check for 3.3 volts at the output.

A most common occurrence, that will prove unnerving, is when the current limit set on the source supply is insufficient for the load. The result is similar to having the high source impedance referred to earlier. The interaction of the source supply folding back and the evaluation board going into undervoltage shutdown will start an oscillation, or chatter, that may have undesirable consequences.

A quick efficiency check is the best way to confirm that everything is operating properly. If something is amiss you can be reasonably sure that it will affect the efficiency adversely. Few parameters can be incorrect in a switching power supply without creating losses and potentially damaging heat.

9 Over Current Protection

The evaluation board is configured with hiccup over-current protection. In the event of an output overload (approximately 25A) the unit will discharge the SS capacitor, which disables the power stage. After a delay, programmed by the RES capacitor, the SS capacitor is released. If the overload condition persists, this process is repeated. Thus, the converter will be in a loop of shot bursts followed by a sleep time in continuous overload conditions. The sleep time reduces the average input current drawn by the power converter in such a condition and allows the power converter to cool down.

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10 Performance Characteristics

Once the circuit is powered up and running normally, the output voltage is regulated to 12V with the accuracy determined by the feedback resistors and the voltage reference. The frequency of operation is selected to be 420 kHz, which is a good comprise between board size and efficiency. Please refer to Figure 2 for efficiency curves.

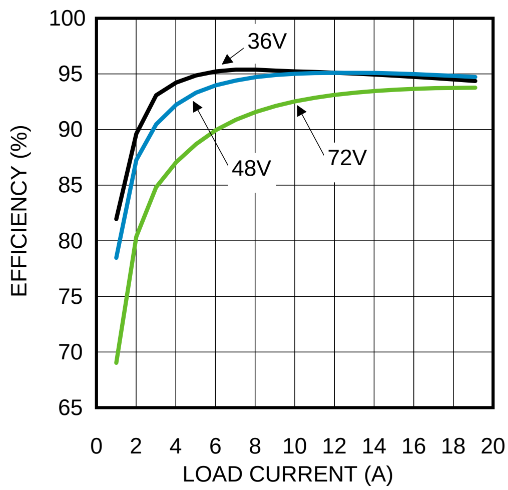
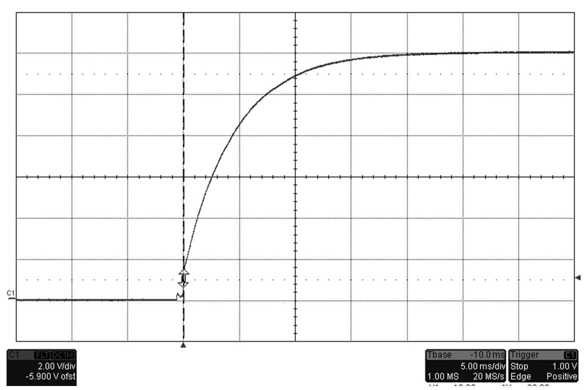


Figure 2. Typical Efficiency Curves

When applying power to the LM5045 evaluation board a certain sequence of events occurs. Soft-start capacitor values and other components allow for a minimal output voltage for a short time until the feedback loop can stabilize without overshoot. Figure 3 shows the output voltage during a typical start-up with a 48V input and a load of 25A. There is no overshoot during start-up.



Output Current = 6A
Trace 1: Output Voltage Volts/div = 2V
Horizontal Resolution = 5.0 ms/div

Figure 3. Soft-Start

Figure 4 shows minimal output voltage droop and overshoot during the sudden change in output current shown by the lower trace.

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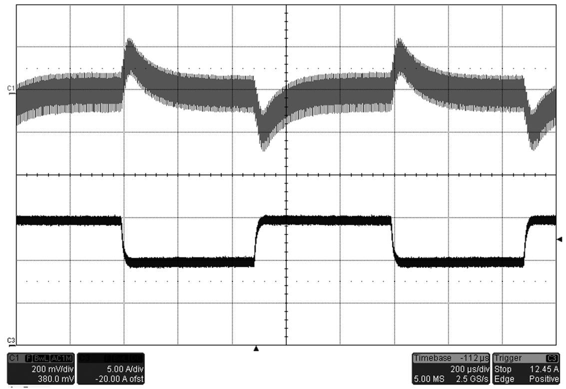
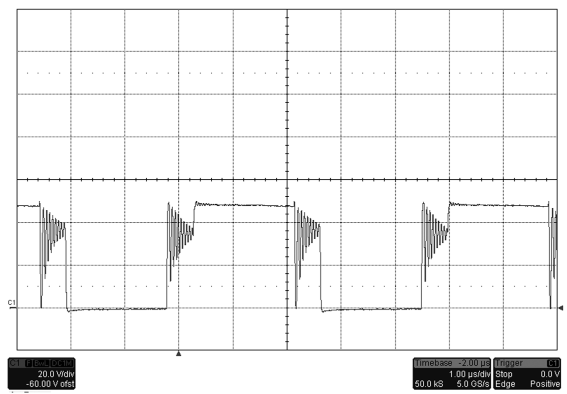


Conditions: Input Voltage = 48V
Output Current = 5A
Upper Trace: Output Voltage Volts/div = 200mV
Lower Trace: Output Current = 10A to 15A to 10A
Horizontal Resolution = 200 µs/div

Figure 4. Transient Response

Figure 5 and Figure 6 show the typical SW node voltage waveforms with a 20A load. Figure 5 shows an input voltage represents an input voltage of 48V and Figure 6 represents an input voltage of 72V.



Conditions: Input Voltage = 48V, Output Current = 20A
Trace 1: Q1 Drain Voltage Volts/div = 20V
Horizontal Resolution = 1µs/div

Figure 5. Switch Node Waveforms

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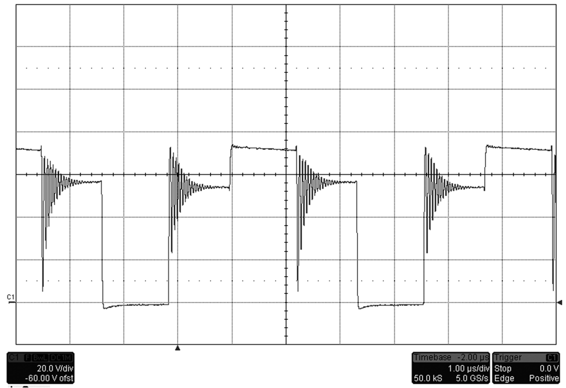
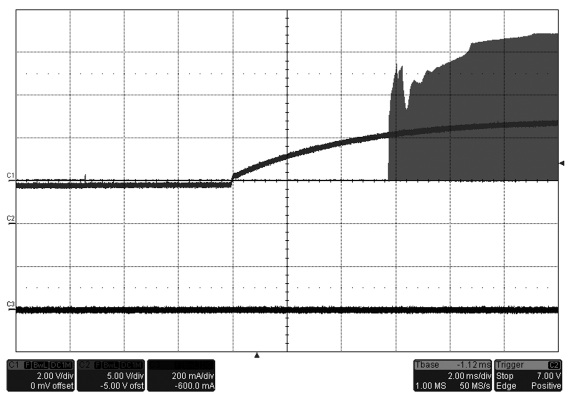


Conditions: Input Voltage = 72V
Output Current = 20A
Trace 1: Q1 Drain Voltage Volts/div = 20V
Horizontal Resolution = 1 µs/div

Figure 6. Switch Node Waveforms

Figure 7 shows a typical startup of the reference into a 5V pre-biased load.



Conditions: Input Voltage = 48V, Output Pre-Bias = 5V
Trace 1: SR Gate Voltage Volts/div = 2V
Trace 2: Output Voltage Volts/div = 5V
Trace 3: Output Current Amps/div = 200mA

Figure 7. Soft-Start Into 5V Pre-Biased Load

Conversion to Phase-Shifted Full-Bridge Topology

The LM5045 reference board can be turned into a phase shifted full-bridge by swapping the LM5045 full-bridge controller with the LM5046 phase shifted full-bridge controller. However, it is advised to rearrange the windings in the power transformer such that the leakage inductance is increased. Higher leakage inductance will aid in achieving ZVS. Leakage inductance can be increased by not interleaving the primaries and secondary's of the power transformer.

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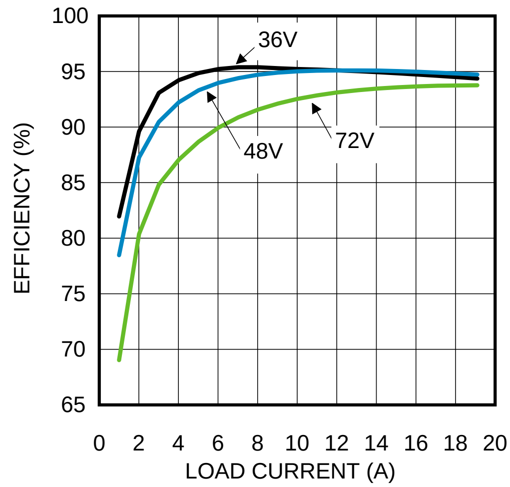

Figure 8. Efficiency Using the PSFB Approach

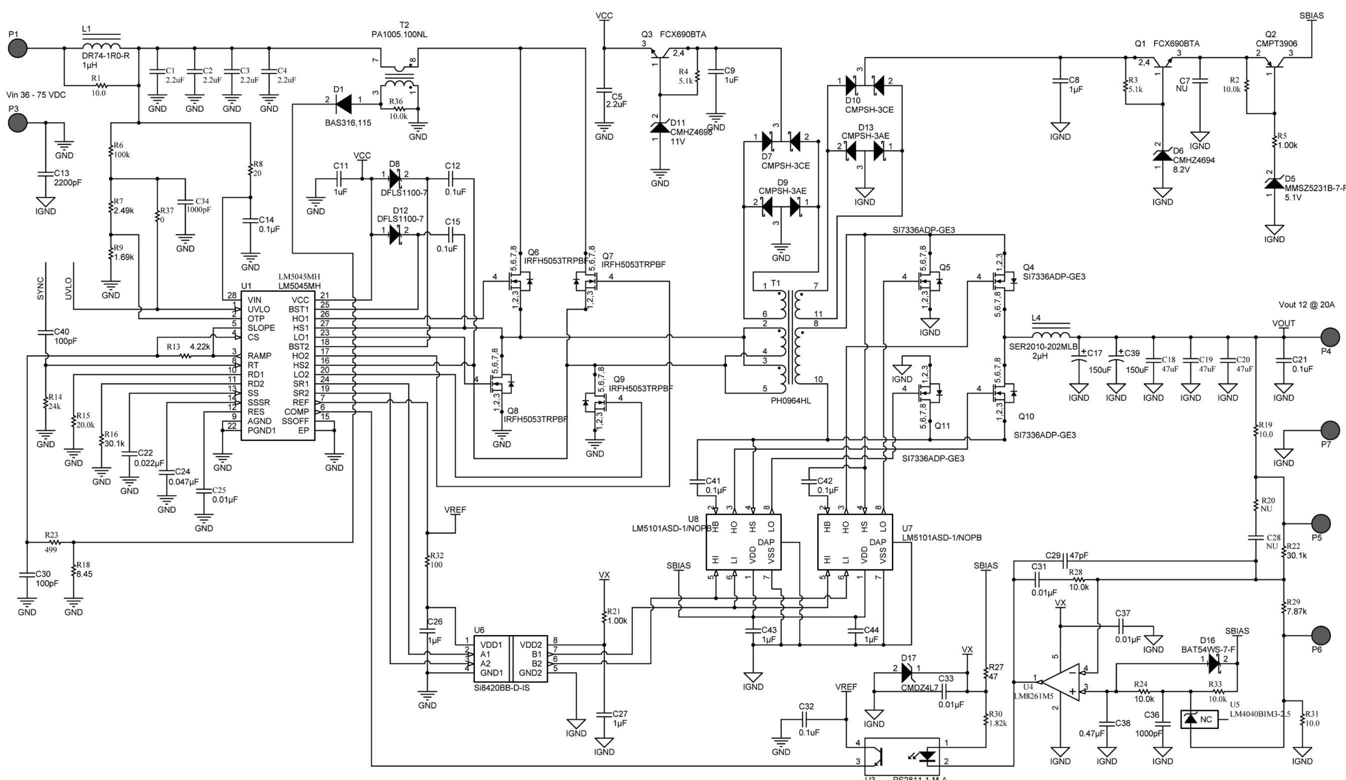

Figure 9. Application Circuit: Input 36V to 75V, Output 12V at 20A

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11 Bill of Materials

Item	Designator	Description	Manufacturer	Part Number
1	C1, C2, C3, C4	CAP, CERM, 2.2uF, 100V, +/-10%, X7R, 1210	MuRata	GRM32ER72A225KA35L
2	C5	CAP, CERM, 2.2uF, 16V, +/-10%, X7R, 0805	MuRata	GRM21BR71C225KA12L
3	C8, C9	CAP, CERM, 1uF, 50V, +/-10%, X7R, 0805	MuRata	GRM21BR71H105KA12L
4	C11	CAP, CERM, 1uF, 16V, +/-10%, X7R, 0603	TDK	C1608X7R1C105K
5	C12, C15, C21, C32	CAP, CERM, 0.1uF, 25V, +/-10%, X7R, 0603	AVX	06033C104KAT2A
6	C13	CAP, CERM, 2200pF, 2000 V, +/-10%, X7R, 1808	Johanson Dielectrics	202R29W222KV4E
7	C14, C41, C42	CAP, CERM, 0.1uF, 100V, +/-10%, X7R, 0603	MuRata	GRM188R72A104KA35D
8	C17, C39	CAP TANT 150uF 16V 20% SMD	KEMET	T530X157M016ATE015
9	C18, C19, C20	CAP, CERM, 47uF, 16V, +/-20%, X5R, 1210	MuRata	GRM32ER61C476ME15L
10	C22	CAP, CERM, 0.022uF, 16V, +/-10%, X7R, 0402	TDK	C1005X7R1C223K
11	C24	CAP, CERM, 0.1uF, 6.3V, +/-10%, X5R, 0402	TDK	C1005X5R0J104K
12	C25, C31, C33, C37	CAP, CERM, 0.01uF, 16V, +/-10%, X7R, 0402	TDK	C1005X7R1C103K
13	C26, C27, C43, C44	CAP, CERM, 1uF, 16V, +/-20%, X7R, 0805	MuRata	GRM21BR71C105MA01L
14	C29	CAP, CERM, 47pF, 50V, +/-5%, C0G/NP0, 0402	MuRata	GRM1555C1H470JZ01
15	C30, C40	CAP, CERM, 100pF, 50V, +/-5%, C0G/NP0, 0603	TDK	C1608C0G1H101J
16	C34, C36	CAP, CERM, 1000pF, 25V, +/-5%, C0G/NP0, 0402	TDK	C1005C0G1E102J
17	C38	CAP CER .47uF 6.3V X5R 0402	TDK	C1005X5R0J474K
18	D1	Diode, Ultrafast, 100V, 0.25A, SOD-323	NXP Semiconductor	BAS316,115
19	D5	Diode, Zener, 5.1V, 500mW, SOD-123	Diodes Inc.	MMSZ5231B-7-F
20	D6	Diode, Zener, 8.2V, 500mW, SOD-123	Central Semiconductor	CMHZ4694
21	D7, D10	Diode, Schottky, 40V, 0.2A, Common Cathode, SOT-23	Central Semiconductor	CMPSH-3CE
22	D8, D12	Vr = 100V, Io = 1A, Vf = 0.77V	Diodes Inc.	DFLS1100-7
23	D9, D13	Diode, Schottky, 40V, 0.2A, Common Anode, SOT-23	Central Semiconductor	CMPSH-3AE
24	D11	Diode, Zener, 11V, 500mW, SOD-123	Central Semiconductor	CMHZ4698
25	D16	Vr = 30V, Io = 0.2A, Vf = 0.7V	Diodes Inc.	BAT54WS-7-F
26	D17	Low Level Zener Diode, 4.7V, 250mW, SOD-323	Central Semiconductor	CMDZ4L7
27	L1	Inductor, Shielded Drum Core, Ferrite, 1uH, 5.39A, 0.0099 ohm, SMD	Coiltronics	DR74-1R0-R
28	L4	PCB Pin	Coilcraft	SER2010-202MLB

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Item	Designator	Description	Manufacturer	Part Number
29	P1, P3, P5, P6	PCB Pin	Mill-Max	3104-2-00-34-00-00-08-0
30	P4, P7	PCB Pin	Mill-Max	3231-2-00-34-00-00-08-0
31	Q1, Q3	Transistor, NPN, 45V, 1A, SOT-89	Diodes Inc.	FCX690BTA
32	Q2	Transistor, PNP, 40V, 0.2A, SOT-23	Central Semiconductor	CMPT3906
33	Q4, Q5, Q10, Q11	MOSFET, N-CH, 30V, PowerPAK SO-8	Texas Instruments	CSD17303Q5
34	Q6, Q7, Q8, Q9	MOSFET, N-CH, 100V, 9.3A, PQFN 8L 5x6 A	International Rectifier	IRFH5053TRPBF
35	R1	RES, 10.0 ohm, 1%, 0.125W, 0805	Vishay-Dale	CRCW080510R0FKEA
36	R2, R24, R28, R33, R36	RES, 10.0k ohm, 1%, 0.063W, 0402	Vishay-Dale	CRCW040210k0FKED
37	R3, R4	RES, 5.1k ohm, 5%, 0.125W, 0805	Panasonic	ERJ-6GEYJ512V
38	R5	RES, 1.00k ohm, 1%, 0.125W, 0805	Vishay-Dale	CRCW08051K00FKEA
39	R6	RES, 100k ohm, 1%, 0.125W, 0805	Vishay-Dale	CRCW0805100KFKEA
40	R7	RES, 2.49k ohm, 1%, 0.063W, 0402	Vishay-Dale	CRCW04022K49FKED
41	R8	RES, 20 ohm, 5%, 0.125W, 0805	Panasonic	ERJ-6GEYJ200V
42	R9	RES, 1.69k ohm, 1%, 0.063W, 0402	Vishay-Dale	CRCW04021K69FKED
43	R13	RES, 4.22k ohm, 1%, 0.063W, 0402	Vishay-Dale	CRCW04024K22FKED
44	R14	RES, 24k ohm, 5%, 0.063W, 0402	Vishay-Dale	CRCW040224k0JNED
45	R15	RES, 20.0k ohm, 1%, 0.063W, 0402	Vishay-Dale	CRCW040220k0FKED
46	R16, R22	RES, 30.1k ohm, 1%, 0.063W, 0402	Vishay-Dale	CRCW040230K1FKED
47	R18	RES, 8.45 ohm, 1%, 0.063W, 0402	Vishay-Dale	CRCW04028R45FKED
48	R19, R31	RES, 10.0 ohm, 1%, 0.063W, 0402	Vishay-Dale	CRCW040210R0FKED
49	R21, R23	RES, 499 ohm, 1%, 0.063W, 0402	Vishay-Dale	CRCW0402499RFKED
50	R27	RES 47 OHM .25W 5% 0603 SMD	Vishay	CRCW060347R0JNEAHP
51	R29	RES, 7.87k ohm, 1%, 0.063W, 0402	Vishay-Dale	CRCW04027K87FKED
52	R30	RES, 1.82k ohm, 1%, 0.063W, 0402	Vishay-Dale	CRCW04021k82FKED
53	R32	RES, 100 ohm, 1%, 0.063W, 0402	Vishay-Dale	CRCW0402100RFKED
54	R37	RES, 0 ohm, 5%, 0.063W, 0402	Vishay-Dale	CRCW04020000Z0ED
55	T1	High Frequency Planar Transformer	Pulse	PA3542NL
56	T2	SMT Current Sense Tranformer	Pulse Engineering	PA1005.100NL
57	U1	Full-Bridge Controller	Texas Instruments	LM5045MH
58	U3	Low Input Current, Hight CTR Photocoupler	NEC	PS2811-1-M-A

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Item	Designator	Description	Manufacturer	Part Number
59	U4	RRIO, High Output Current & Unlimited Cap Load Op Amp in SOT23-5	Texas Instruments	LM8261M5
60	U5	Precision Micropower Shunt Voltage Reference, 3-pin SOT-23	Texas Instruments	LM4040BIM3-2.5
61	U6	Digital Isolator	Texas Instruments	ISO7420FED
62	U7, U8	3A High Voltage High-Side and Low-Side Gate Driver, 8 pin LLP	Texas Instruments	LM5101ASD-1/NOPB
63	C7	CAP, CERM, 3.3uF, 16V, +/-10%, X5R, 0805	MuRata	GRM21BR61C335KA88L(optional)

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11.1 PCB Layouts

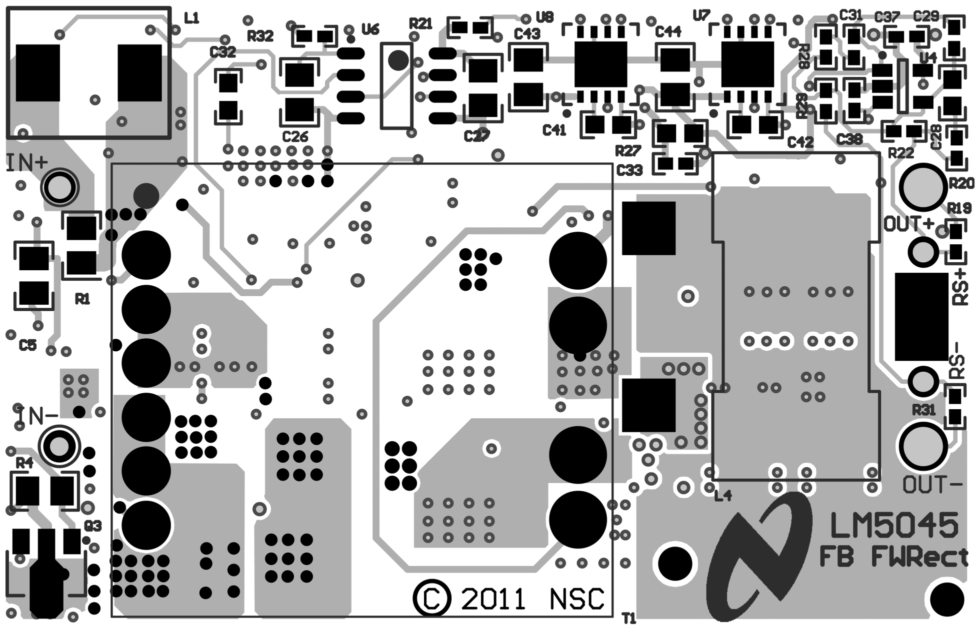

Figure 10. Top Side Assembly

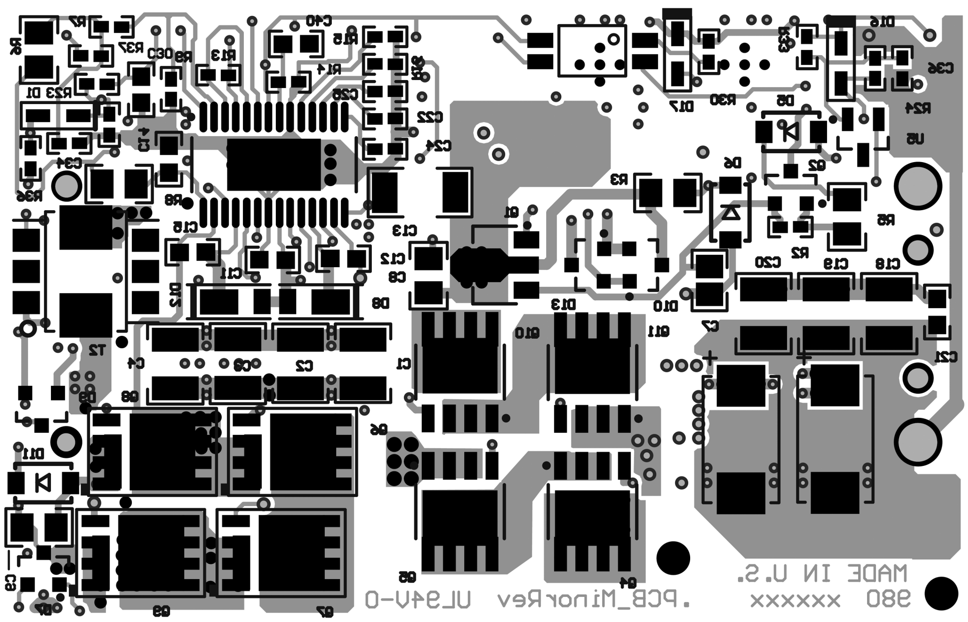

Figure 11. Bottom Side Assembly

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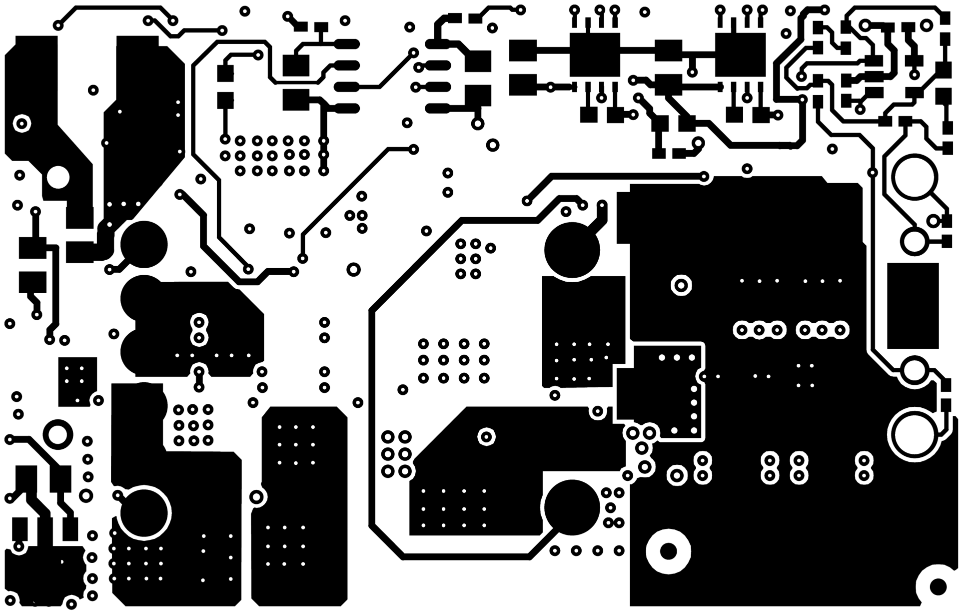

Figure 12. Layer 1 (Top Side)

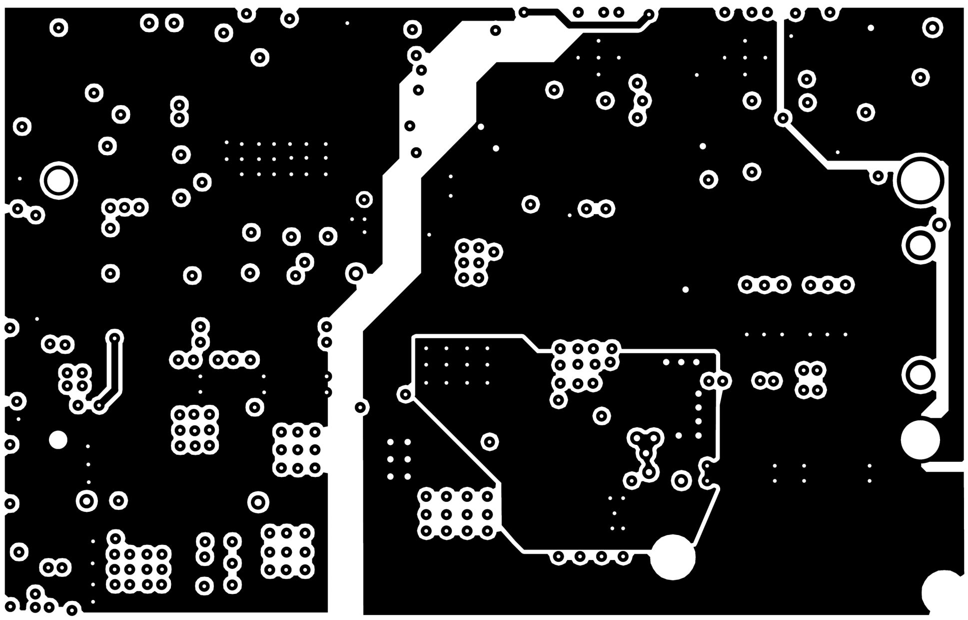

Figure 13. Layer 2

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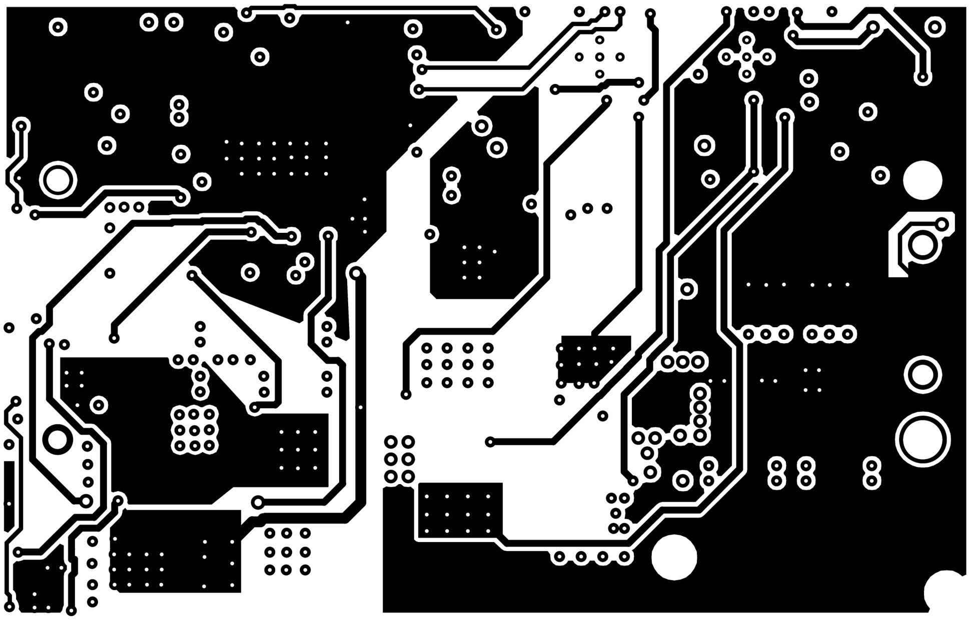

Figure 14. Layer 3

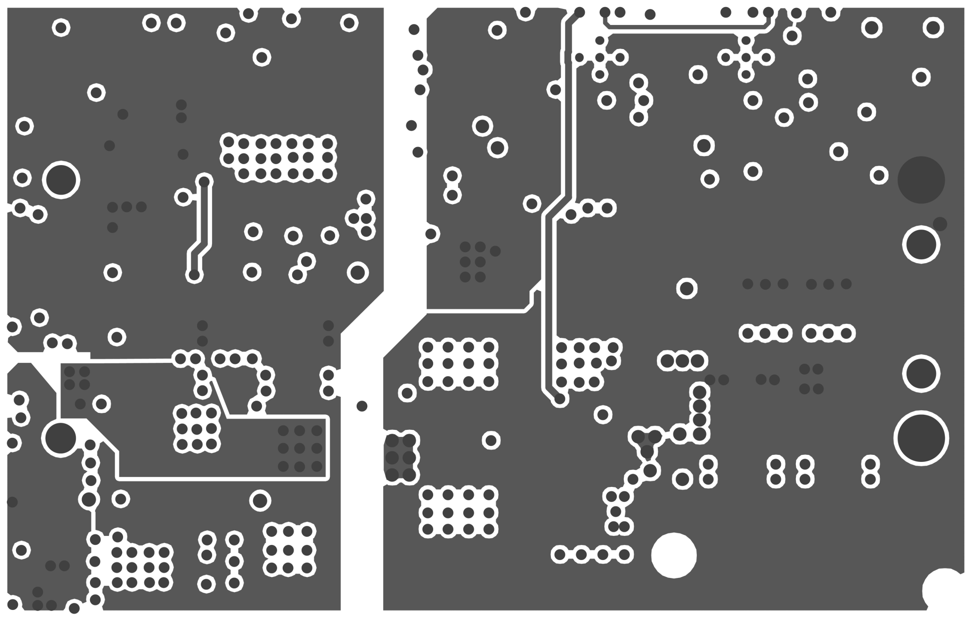

Figure 15. Layer 4

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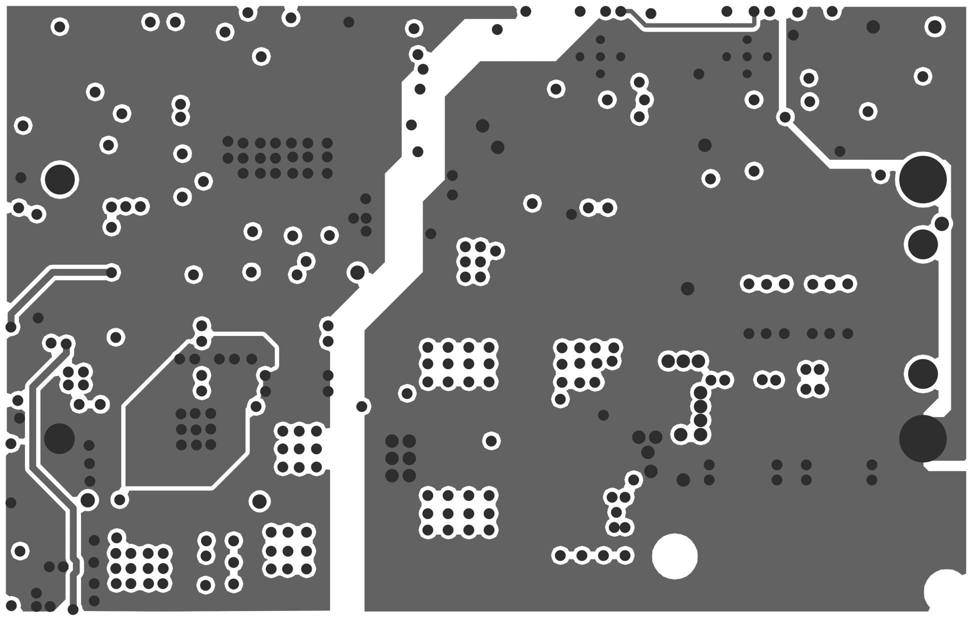

Figure 16. Layer 5

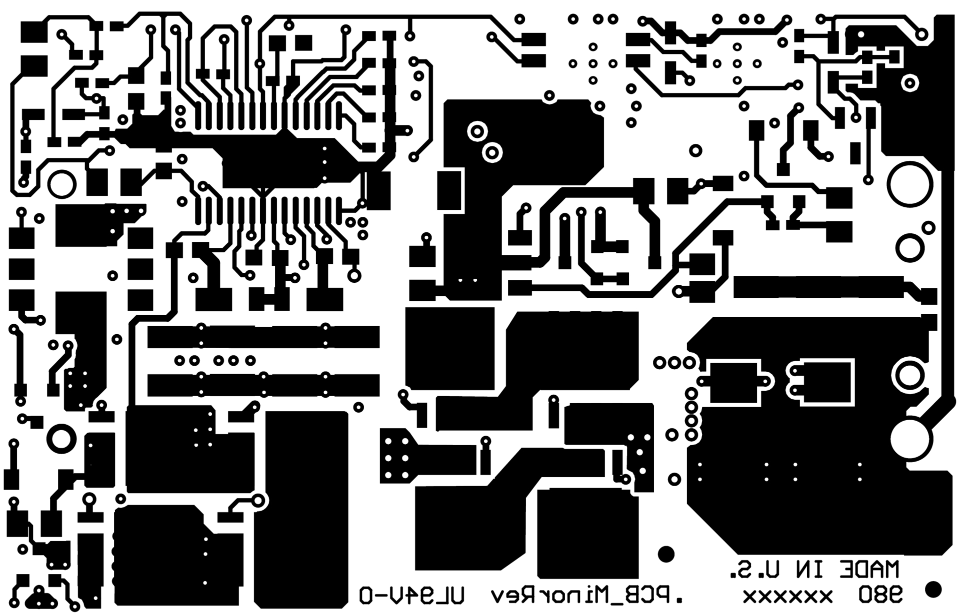

Figure 17. Layer 6 (Bottom Side)

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Amplifiers	amplifier.ti.com	Communications and Telecom	www.ti.com/communications
Data Converters	dataconverter.ti.com	Computers and Peripherals	www.ti.com/computers
DLP® Products	www.dlp.com	Consumer Electronics	www.ti.com/consumer-apps
DSP	dsp.ti.com	Energy and Lighting	www.ti.com/energy
Clocks and Timers	www.ti.com/clocks	Industrial	www.ti.com/industrial
Interface	interface.ti.com	Medical	www.ti.com/medical
Logic	logic.ti.com	Security	www.ti.com/security
Power Mgmt	power.ti.com	Space, Avionics and Defense	www.ti.com/space-avionics-defense
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